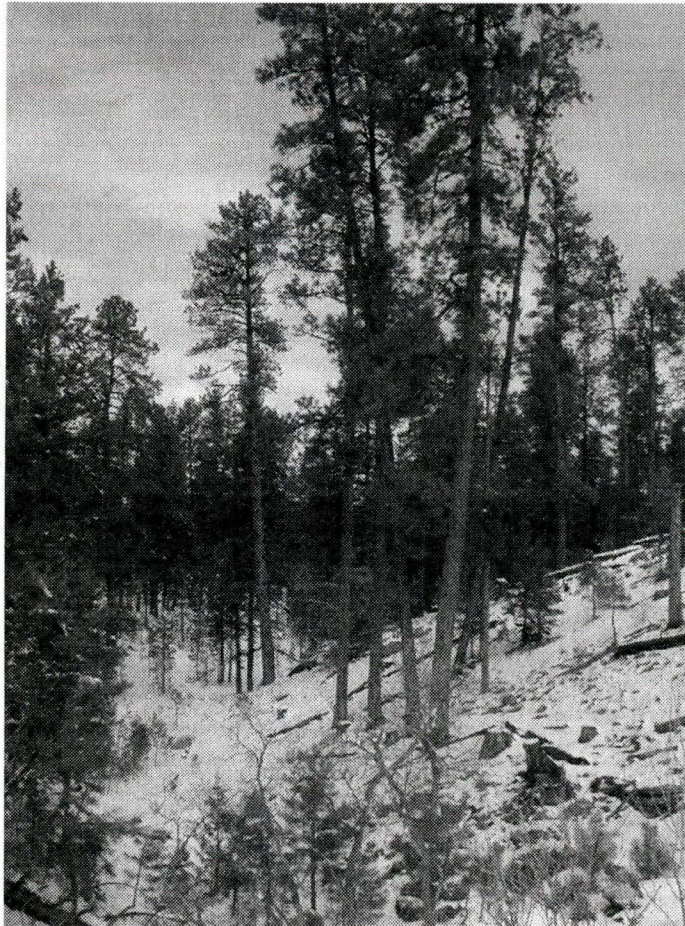


FIRE AND PANDORA MOTH HISTORY IN
NORTHERN ARIZONA

Joint Venture Agreement 00-JV-11221605-192

Fire and Pandora Moth History in Northern Arizona



**Final Report for
Joint Venture Agreement 00-JV-11221605-192**

Between

**USDA Forest Service
Rocky Mountain Research Station
Research Work Unit Number 4152**

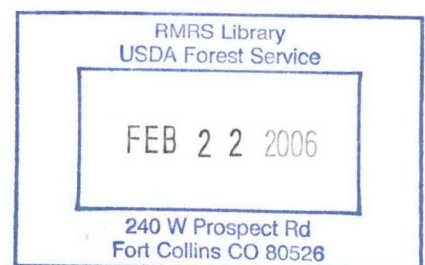
And

**The University of Arizona
Laboratory of Tree-Ring Research**

30 September 2005

Report prepared by

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I. Abstract

Tree-ring analysis was used to investigate past defoliation by pandora moth (*Coloradia pandora* Blake (Lepidoptera: Saturniidae)) in stands of ponderosa pine in the vicinity of Jacob Lake Arizona and sites along the north rim of the Grand Canyon of the Colorado River. Host and non-host chronologies were developed from 7 sites, 3 host and 4 non-host. Additionally, fire-scarred tree sections were collected from stumps within the host tree sites to examine potential fire-insect interactions. The analysis documented at least one probable past episode of Pandora moth defoliation in the 19th century along with several possible additional periods in the 18th and 19th centuries. Cores from both the North Rim sites collected by Fulé that were analyzed for this project and the host sites in the Jacob Lake area showed evidence of growth suppression around 1880 similar to that caused by Pandora moth larval feeding. However the occurrence of a widespread fire or fires in 1879 that was associated with mortality in the Jacob Lake stands provides a competing cause for this period of suppressed growth. Drought may have also played a role in this period as 1879 and 1880 are regional drought years (Cook et. al. 1999). The analysis with program OUTBREAK also highlighted drought interaction with the 1970-74 regional drought leading to host tree growth reductions relative to controls that were misidentified as defoliation periods, smearing the clear signal of the 1980 pandora moth irruption. While there was some suggestion of fire-insect interaction similar to that documented by Speer et. al. (2001) the lack of clear and consistent reconstructed episodes of feeding prevented any definitive conclusion. Additional sampling within the zone affected by the 1980 outbreak and adjacent areas of both host trees and fire scars has the potential to produce a clearer picture of insect and fire dynamics in this region.

Overview

Pandora moth (*Coloradia pandora* Blake (Lepidoptera: Saturniidae)) is an important defoliator of pines in western forests, and is the only significant defoliator of ponderosa pine (*Pinus ponderosa* Laws) in Arizona. Outbreaks occur only in areas with soils loose enough for the larvae to bury themselves for pupation, which include Arizona's widespread pumice soils. Several outbreaks have occurred on the Kaibab Plateau north of the Grand Canyon (Miller & Wagner 1984, 1989; Schmid et al. 1982a,b). Generally, outbreaks in the West are thought to occur at intervals of about 20 to 30 years, with a duration of 6 to 8 years (Furniss and Carolin 1977; Patterson 1929). The insect has a 2-year life cycle, so defoliation generally occurs every other year during the outbreak. The pattern of alternate year defoliation, and lack of feeding on the terminal buds, permits most trees to survive except during the most severe outbreaks.

Because Pandora moth does not usually cause extensive tree mortality, it does not directly increase fire hazard. However, recent work indicates that fire frequency is reduced during Pandora moth outbreaks in south-central Oregon (Speer et al. 2001). This

is possibly caused by insect consumption of needles, causing subsequent reduction in fine fuels on the forest floor. More Pandora moth pupae are found in open- than in closed-canopy stands (Miller and Wagner 1984), and defoliation severity increases with tree spacing (Cochran 1998), indicating that Pandora moth may have a role in regulating stand density. Pandora moth outbreaks and a regime of frequent surface fires would both promote widely-spaced, open-canopy forests such as are assumed to have characterized the pre-settlement forest on the Kaibab Plateau.

This project is a pilot study undertaken to determine the feasibility of reconstructing joint Pandora moth and fire histories from tree-ring material on the Kaibab Plateau. Project objectives include: a) evaluation of the feasibility of reconstructing joint Pandora moth and fire histories from tree-ring materials, b) determination of the duration and temporal variability in Pandora moth outbreaks on the Kaibab Plateau, c) analyze the variability in the Pandora moth disturbance history for associations with fire history patterns, and d) evaluate the spatial variability of Pandora moth outbreaks within the temporal framework. In the latter objective, we are trying to determine if outbreaks occurred in the past in the same areas where they have occurred in the recorded historic period. Existing samples taken by Pete Fulé (Fulé et al. 2000) without regards to contemporary Pandora moth outbreak history have been augmented by additional site-based samples. Because of the preliminary nature of the work, we do not expect to fully achieve these objectives, though we hope to achieve significant progress and/or results.

Methods

Jacob Lake reconstruction:

Tree-ring samples were collected during two field trips and developed into seven site chronologies. Ponderosa pine increment cores were collected from three sites near Jacob Lake for reconstructing site-based fire history and Pandora moth chronologies (JLN, JLS, and BLR). Two non-host sites of *Pinus edulis* were collected, one north (CPW) and one east (EKP) of the host sites. The ponderosa pine sites incurred different levels and duration of Pandora moth defoliation during the 1978-1982 outbreak (which was documented by Schmid et al. 1982a, b; Schmid and Bennett 1988; and Miller and Wagner 1989).

Fire-scarred sections were also collected at each of the three host chronology sites.

Additionally, two non-host tree-ring chronologies were developed from sites within Grand Canyon National Park near Fulé et al.'s Fire Point age structure/fire history plot (FPP piñon pine and FPF Douglas-fir).

Ring widths were measured to the nearest 0.01 mm and the crossdating verified with the computer program COFECHA (Holmes 1986, Grissino-Mayer and Fritts 1997). The dated ring-width series from each core was standardized with the computer program ARSTAN (Cook and Holmes 1986; Grissino-Mayer and Fritts 1997) in order to remove age-related

trends in growth. Host and non-host chronologies were compared using the computer program OUTBREAK (Holmes and Swetnam 1996), to develop growth departure chronologies, as done elsewhere for coniferous defoliators (Jardon et al. 1994; Speers et al. 2001; Swetnam et al. 1985, 1995; Swetnam and Lynch 1989, 1993). Fire scar samples were dated and fire-scar chronologies constructed and compared to the insect outbreak chronologies for commonalities.

Grand Canyon N.P. material

Fulé et al. reconstructed fire history for a remote area of the North Rim of the Grand Canyon that has been less affected by post-settlement management practices than most of the Southwestern ponderosa pine forests. Fire return intervals, based on fire years in which 25% or more of the recording trees were scarred, ranged from 6.4 to 9.5 years. Increment core samples were taken from trees on the sites, and tree-ring growth reductions and anatomical features similar to those identified by Speer et al. (2001) as caused by Pandora moth larval feeding are apparent in many of these cores. A subset of these cores was cross-dated and examined for evidence of growth suppressions that typify the effects of Pandora moth feeding.

Results

Increment cores were cross-dated, measured and standardized using a 100 year cubic smoothing spline. This standardization method was chosen to preserve the high and medium frequency growth variation in response to annual climate variability and insect feeding while removing growth trends due to age related factors, stand dynamics or low-frequency climate variation (Swetnam et. al 1995). One chronology developed from Douglas-fir as a potential non-host control proved to be unsuitable due to pronounced effects of feeding by spruce budworm evident in the cores. The final chronologies are presented in Figure 1. The higher coherence of the CPW and FPP piñon control chronologies relative to that developed for EKP, and a better inferred relationship with annual precipitation (Fig. 2), led to the combining of the former two into a single timeseries to be used in the OUTBREAK correction procedure. A simple regression between the two-site chronology and annual precipitation had an r^2 value of 0.41. Regression of the host chronologies with the precipitation values showed a positive but much weaker relationship undoubtedly a result of the growth reductions caused by larval feeding. The BLR site showed the strongest relationship among the three sites, confirming the less dramatic effect of the Pandora moth feeding there as revealed in the subsequent analysis. While the EKP non-host chronology was not utilized in the analysis one tree was cored there that was more than 900 years old and considerable remnant material was present suggesting the possibility of developing a 1000 year long from this site. Two remnant samples collected from this site also had inner dates in the 10 hundreds A.D.

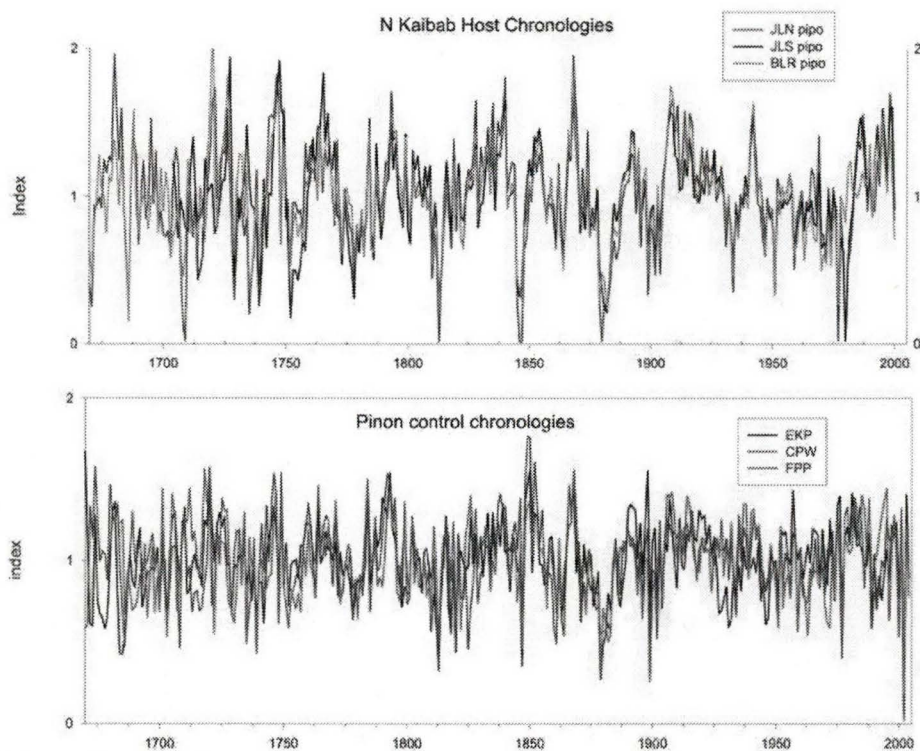


Figure 1a and 1b.

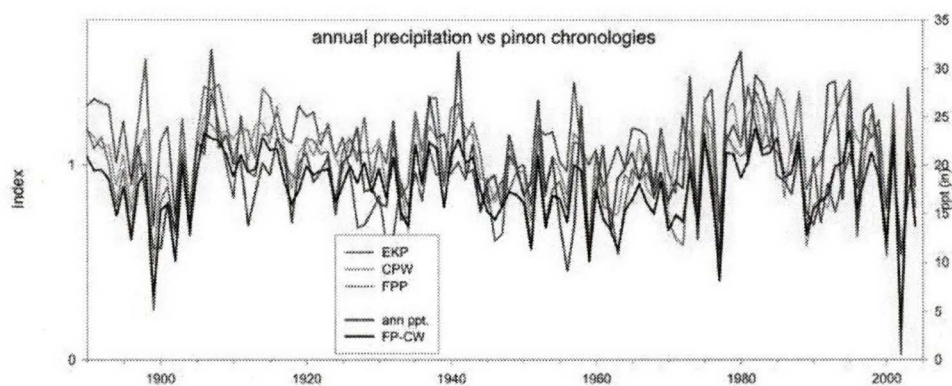


Figure 2.

Fire-scarred sections

Fire-scarred specimens were dated and used to obtain a fire chronology for each site, and only two of the sample trees (at the BLR site) could not be dated. The fire chronology at JLN includes 12 trees, JLS 7 trees and three trees from BLR. The fire chronologies developed from these samples are presented in figure 3 and show a typical southwestern pattern of frequent low or mixed-intensity fires that ceased around the end of the 19th century.

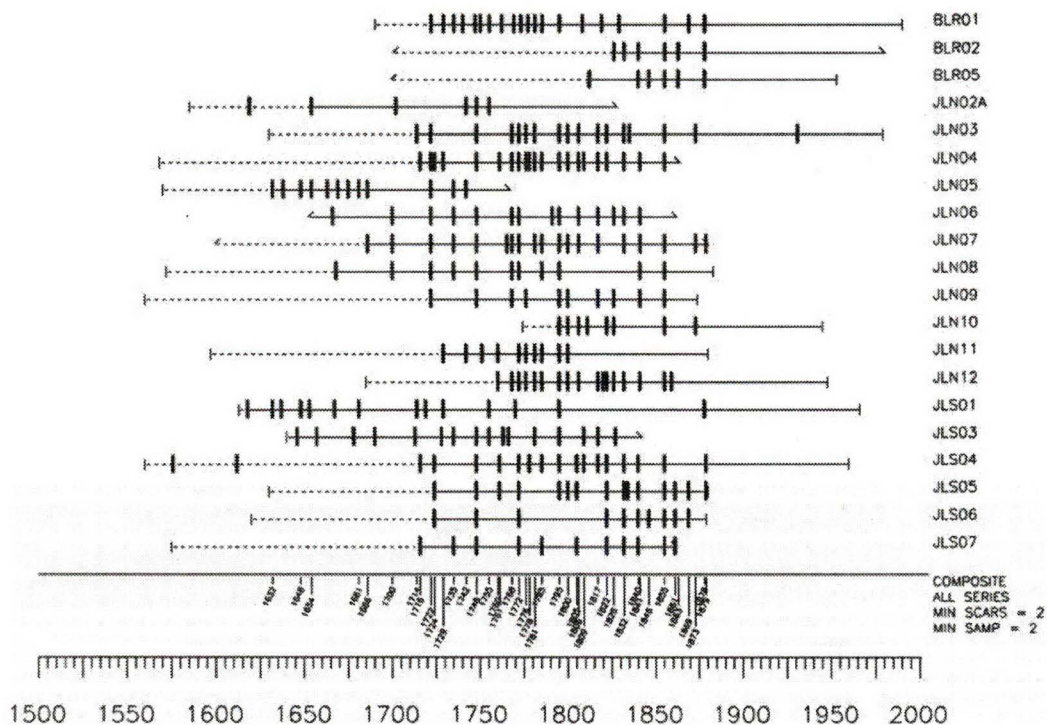


Figure 3.

Some inter-site synchrony was observed, particularly between the adjacent JLN and JLS sites. Additionally, a widespread fire in 1879 was recorded at all sites and concurrent clustered death dates suggest a particularly intense surface fire occurred on this date. Fulé's data also show a very widespread fire in 1879. This event bears on the interpretation of the results below.

Growth reduction analysis

Cores at each site have been used to identify possible Pandora moth outbreaks, using wood anatomical evidence, observation of tree-ring patterns and comparison against the control chronology using the program OUTBREAK (Holmes & Swetnam 1996). Visual analysis suggested periods of pandora moth defoliation that are shown in figure 4 as indicated by the single hatched bars overlaid on the tree-ring timeseries. Coarse double-hatched bars show periods of host series depressed growth that were also associated with anatomical features linked with defoliating insect feeding (Speer et. al. 2001, Margolis et. al. 2001). The fine double-hatched bar placed around 1980 highlights the effect of the well documented modern outbreak (Schmidt and Bennett 1988).

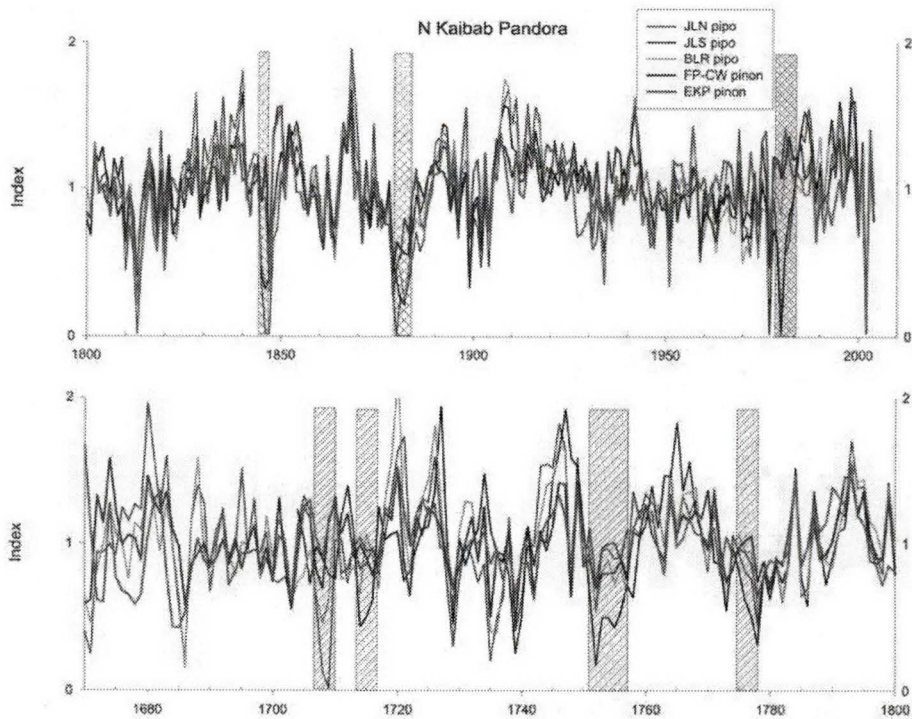


Figure 4.

Program OUTBREAK was run with the default parameters and the result is shown in figure 5 with the tree-ring timeseries overlaid.

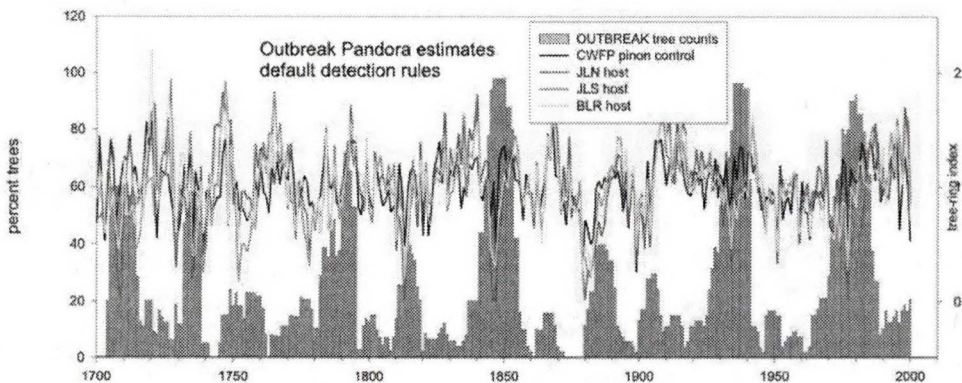


Figure 5.

As can be seen in the figure the two clearest episodes are the documented event centered on 1980 and a period in the mid to late 1840s. There is an additional episode with strong departures indicated in the late 1930s, however there is no documentation of such an event in the area. A footnote to a report does mention an episode in the "Prescott Forest" (cit.) around this time related as a personal communication but no specifics were provided and no other reference was located. This period is considered as "possible, but no documentation". The documented period of 1978-84 appears strongly but the interval reconstructed begins too early, around 1970 where the host series and control series diverge during a drought period that preceded the moth outbreak. Given these issues the

confidence in this reconstruction is low. In an attempt to tighten up the program's output for the modern period the identification trigger values were changed from their default settings. Default parameters of 1.28 std. dev. for growth departure and 5 years minimum duration were changed to 2 std. dev. and 6 years minimum duration. The result of this alteration is presented below in figure 6.

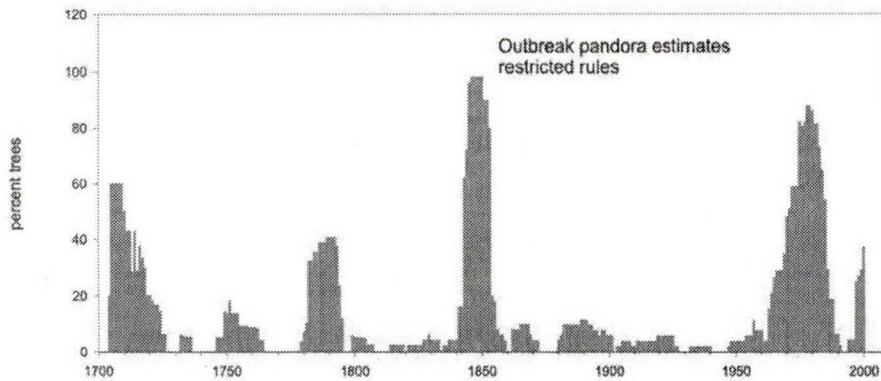


Figure 6.

Only the 1978-84 episode and the 1840s remain in addition to 3 18th century periods. However, the 78-84 period is still mis-identified as beginning around 1970. These restrictive rules eliminate all the intervening periods including the 1880 and 1930s and it is not clear that this is appropriate.

A more detailed discussion of the modern episode and two possible historic episodes follows.

The Jacob Lake outbreak (1978-1984)

This is the only reported outbreak at the study area. Trees sampled at JLN and JLS show this period very well. The rings formed in 1978, 1980 and 1982 are very narrow or even

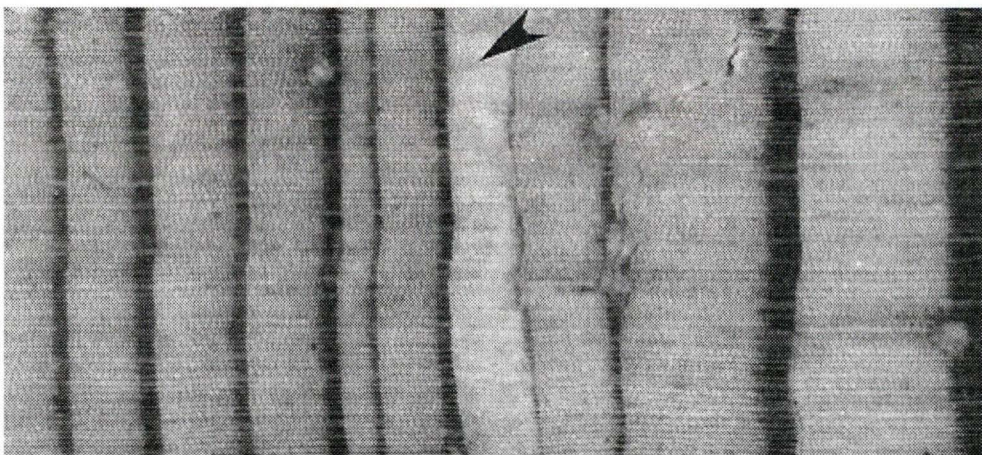


Figure 7. Core showing the white ring growth anomaly.

missing in most of the sampled trees. The year 1980 was missing in a great proportion of the sampled trees at both sites, and only very occasionally more than one missing ring can be identified. The typical pattern of the Pandora moth outbreak, consisting on a ring with thin latewood followed by few years of growth reduction, can

be identified. In addition to this, some of the trees show a very characteristic anatomical pattern that has been analyzed more carefully (Fig. 7). During the outbreak period, one of the rings has a paler colour, almost white; this appearance was caused by a much lower lignification in the earlywood. A closer look at these rings reveals irregular-shaped earlywood tracheids; this kind of pattern can be seen on very extreme defoliation years caused by insect outbreaks, as was described by Schweingruber (2001). This is not restricted to the growth reduction in 1978-1984, but can be observed very occasionally on other periods as in the 1880s. Light or "white" rings were seen in some of the Pandora moth outbreaks described by Speer et al. (2001), in other coniferous defoliator signals (Filion and Cournoyer 1995; Girardin et al. 2001; Krause & Morin 1995; Kulman et al. 1963) and aspen (Hogg et al. 2002; Margolis et al. 2001).

Figure 6. Tree-ring pattern of the Jacob Lake outbreak showing a whiter ring in 1980 during an outbreak.

On the other hand, most of the trees growing at BLR do not show a clear growth reduction during this period. Most of the trees do not show any clear growth reduction, and only three trees have a locally missing ring for the period (1978-1984), two of them having very reduced growth during the last decades. This result should be expected, as this site was selected because of its less intense infestation levels during this period.

The 1880s growth reduction

This is a very extreme growth reduction period observed at most of the trees at all three sites. The first year of reduction that can be identified is 1879. Missing rings are common within this period (often more than one), especially in 1880 or 1882. The percentage of missing rings at all study cores can be seen on table 1.

Year	JLN	JLS	BLR	CPW	FPP	EKP
1879	5.7%	0.0%	10.3%	4.5%	42%	23%
1880	91.4%	13.3%	5.1%	9.1%	7.0%	6%
1881	28.6%	3.3%	5.1%	4.5%	14%	0.0%
1882	28.6%	10.0%	23.1%	4.3%	0.0%	0.0%
1883	8.6%	0.0%	0.0%	0.0%	0.0%	0.0%
1884	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%
1885	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1886	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 1. Percent of cores with missing rings during the 1880s outbreak at each site.

Sequences of three or more missing rings are not rare, especially for the JLN site. At this site, only three cores do not have a missing ring in 1880, and a sequence of six consecutive missing rings was found in one of the cores (1879-1884). Trees at JLS show fewer missing rings than the other sites, but this could be related to the fact that most trees are younger than in the other sites. A typical pattern of the 1880s reduction is shown on Figure 8.

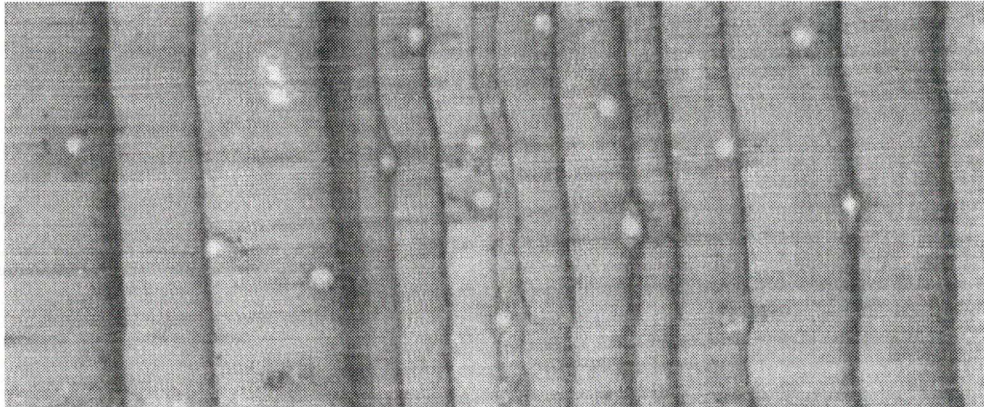


Figure 8. Core showing the 1880s growth reduction.

The duration of the growth reduction is variable. It usually extends from 1879 until 1884, but can last for a longer period, even until 1890. Also, the beginning of the reduction period is difficult to establish. Although 1879 is the first year of the period, it is not easy to say that an outbreak could have occurred this year or one year later. The appearance of the ring in 1879 in several individuals seems to indicate the occurrence of an important drought, probably beginning in spring. This is very narrow, with very thin latewood by very lignified tracheids in the earlywood, that causes the ring to be darker than usual. The presence of a whiter ring within the reduction period can occasionally be seen.

The control sites also show a growth reduction during this time. This reduction could however be only the reflect of a drought, since it is less severe than in ponderosa pine trees and no characteristic “white” rings are present for the control species.

During the observation of Fulé’s cores, this reduction period was identified in most of the sample plots. Missing rings were also present in most of the observed cores, and sequences of 3-6 missing rings have been dated in some of the selected cores. The above mentioned anatomical patterns were also sometimes observed.

While the evidence of a host-specific growth reduction and associated anatomical characteristics suggest the possibility of Pandora moth defoliation, the occurrence of the very widespread fire of 1879 throughout our collection sites and Fulé’s complicates this conclusion. A number of sampled trees at the JLN site appear to have been killed in this fire suggesting uncharacteristically severe fire behavior. The co-occurrence of drought conditions in 1879 and 1880, well documented in this area by the growth reduction in the

non-host controls, with this fire may be responsible for the growth reductions and growth anomalies observed in both our sites and the North Rim sites collected by Fulé.

The 1840s growth reduction

This period constitutes a short but very extreme growth reduction at the JLN site, although it is also observable at JLS and BLR. In contrast to this, the control chronology only shows a narrow ring in 1847 (which is related to drought) and no missing rings were identified.

Missing rings are common for many trees (Table 3), and even the whole sequence 1845-1846-1847 is often identifiable. The observation of more samples from different sites at this area suggests the possibility of a longer outbreak period that could extend into the 1850s, but this should be confirmed by the analysis of these samples together with other control sites.

Year	JLN	JLS	BLR	CPW	FPP	EKP
1844	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1845	20.0%	15.4%	2.6%	0.0%	0.0%	0.0%
1846	80.0%	23.1%	12.8%	0.0%	0.0%	0.0%
1847	54.3%	7.7%	23.1%	0.0%	0.0%	14%
1848	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 2. Percent of cores with missing rings during the 1840s outbreak at each site.

Once again, the most affected site is JLN, with more than half of the cores having a missing ring for both 1846 and 1847. In this case, no growth reduction is observed at the control site (only the narrow ring related to drought in 1847 is observed).

This episode is by far the clearest candidate for a historic Pandora moth outbreak in the Jacob lake area. All characteristics are present and there are no competing disturbances e.g. fire occurrence or drought.

Fire-pandora moth interaction

Speer et. al. (2001) found that larval feeding probably diminished the effectiveness of surface fire spread by reducing fuels within host forest stands. In order to look for possible fire-moth interactions in the Jacob Lake stands the fire chronology developed for the area was compared to the outbreak reconstruction in Figure 9.

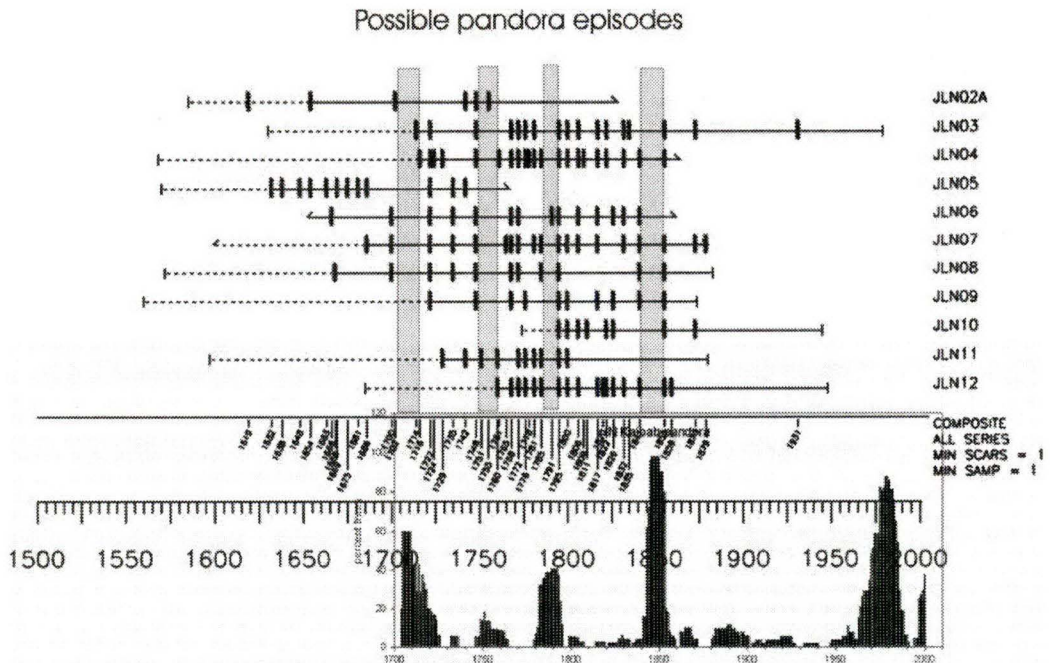


Figure 9.

There is a suggestion that the inferred 18th century and 1840s outbreak do occur in association with reduced fire activity (Fig. 9). However, given the remaining uncertainties with the reconstruction, any firm conclusion is premature.

In addition to the Pandora moth feeding signatures, an additional growth pattern was noted in some trees from all host sites. In trees that established prior to 1700 growth prior to ca 1710 was often suppressed from establishment to that date. At about 1710 a marked growth increase occurred that was sustained for many decades, often for the entire life of the tree (Figure 10.)

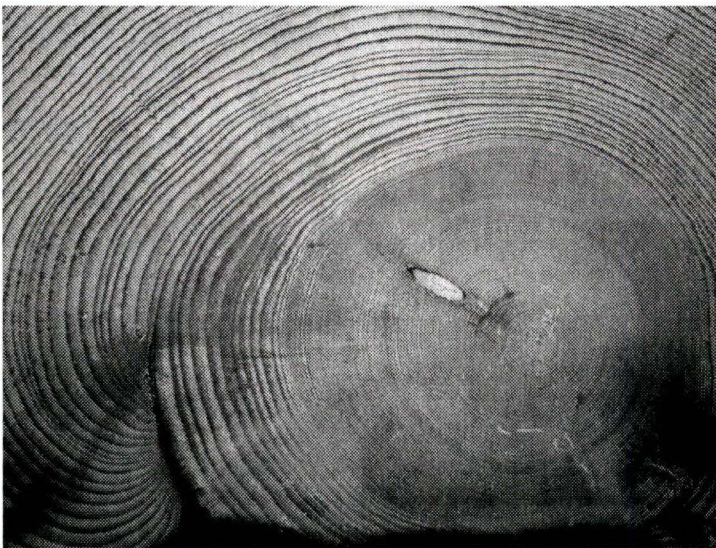


Figure 10.

This growth pattern would be consistent with establishment in a very dense stand and release following a thinning event. While a reasonable cause of such thinning might be fire related mortality no fire scar or other anomaly suggested such an event occurred at this time. This period is not one of severe drought and Pandora moth larval feeding is not noted for causing extensive host mortality. However, given the widespread distribution of samples exhibiting this growth pattern some stand-wide disturbance is indicated.

Discussion

Pandora moth outbreaks seem to occur during or after dry periods in this region, which presents difficulties in discriminating between growth reductions caused by larval feeding and those related to drought without a larger set of control chronologies. The Jacob Lake outbreak (1978-1984) follows the dry years in the 1970s, especially 1977. Also, the 1880s outbreak follows drought in 1879, and the 1840s also include dry years such as 1847. Several growth reductions that have been observed, especially in the 19th century (e.g. 1810s, 1820s or 1860s) are probably not related to Pandora moth larval feeding, as they occur in dry periods confirmed by the non-host chronologies. This could also be the case for the 1790s or previous periods. Speer et al. (2001) found a weak coincidence between drought and Pandora moth outbreaks in south-central Oregon. Success in describing an association between drought and Pandora moth outbreaks, whether the outbreaks occur during or after drought, is necessary for interpretation of the complete insect-climate-fire disturbance history. Results here look very promising, but more rigorous sampling with more sites and larger sample sizes may be necessary to fully describe the insect-climate interaction and the effects on fire periodicity in this region.

Recommendations for follow-up research

- While all increment cores collected for analysis were measured and examined for evidence of feeding by Pandora moth, the fire-scarred sections were not included in this part of the analysis. As a considerable number of these samples established during the 17th century or earlier it would be possible to extend the record available for analysis in the Jacob Lake area for 150 or 200 years.
- Search of archive records might provide additional evidence of previous Pandora moth outbreaks in Arizona. The suggestion that there was an outbreak on the Prescott National Forest in the 1930s is an intriguing anecdote that is of particular interest as the correction procedure applied in this study to detect growth anomalies suggested a departure from expected growth in the 1930s in the Jacob lake samples.
- The tree-ring site "EKP" had both old living trees and remnant material nearly 1000 years old. Such sites are very rare and can provide valuable records of past environmental conditions and trends and changes through time. Additional sampling in this area could both provide a longer control chronology useful in the

current context, however it could also provide more general information about local and regional conditions over the past 10 centuries.

- Spatial variability documented for the 1978-83 Jacob Lake outbreak could be investigated by systematic sampling within the defoliated areas using the intensity maps generated at the time of the outbreak. This could be compared to the 1840s episode to see if the patterns of spatial variability observed were common in past outbreaks, shedding light on Pandora moth irruption dynamics.

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